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Claims

[c1] 1.A zero boiloff cryogen cooled recondensing superconducting magnet assembly including superconducting magnet coils suitable for magnetic resonance imaging comprising:

a cryogen pressure vessel to contain a liquid cryogen reservoir to provide cryogenic temperatures to said magnet coils for superconducting operation;

a vacuum vessel surrounding said pressure vessel and spaced from said pressure vessel;

a first thermal shield surrounding said pressure vessel and spaced from said pressure vessel;

a second thermal shield surrounding said first thermal shield and spaced from said first thermal shield, said second thermal shield intermediate said vacuum vessel and said first shield;

a cryocooler thermally connected by a first and a second thermal interface to said first and second thermal shields, respectively;

a recondenser positioned in the space between said pressure vessel and said first thermal shield and thermally connected by a thermal interface to said cryocooler to recondense, back to liquid, cryogen gas provided from

said pressure vessel; and

means for returning the recondensed liquid cryogen to said pressure vessel;

wherein said second thermal shield surrounding said first thermal shield reduces a radiation heat load from said first thermal shield to said pressure vessel lowering boiloff of cryogen gas under conditions of failure or power off of said cryocooler.

[c2] 2.The zero boiloff superconducting magnet of claim 1, wherein said cryocooler includes at least one of a single, double, and a three stage coldhead.

[c3] 3.The zero boiloff superconducting magnet of claim 2 including a penetration extending through said vacuum vessel to said pressure vessel, said penetration thermally isolated from said coldhead.

[c4] 4.The zero boiloff superconducting magnet of claim 3 including a third thermal interface between said cry-ocooler and said recondenser, and wherein sensible heat from said boiloff of cryogen gas cools down at least one of a coldhead sleeve of said coldhead, said penetration, and said first and second thermal shields.

[c5] 5. The zero boiloff superconducting magnet of claim 4 including tubing disposed on at least one of said cold-

head sleeve and respective said first and second thermal shields in fluid communication with said boiloff of cryogen gas, said tubing in further fluid communication with a pressure relief valve configured to selectively vent said boiloff of cryogen gas.

[c6] 6.The zero boiloff superconducting magnet of claim 5, wherein said tubing includes copper tubing.

[c7] 7.The zero boiloff superconducting magnet of claim 6, wherein said tubing in fluid communication between said first and second thermal shields includes a low conductive transition tubing in order to reduce conduction of heat load during normal operation of said coldhead.

[c8] 8.The zero boiloff superconducting magnet of claim 7, wherein said low conductive tubing connects copper tubing disposed around each of said first and second thermal shields.

[c9] 9.The zero boiloff superconducting magnet of claim 7, wherein said low conductive tubing is a low thermally conductive tubing including stainless steel transition tubing.

[c10] 10.The zero boiloff superconducting magnet of claim 3, wherein said penetration includes a first penetration station and a second penetration station thermally con-

nected by first and second penetration thermal interfaces to said first and second thermal shields, respectively.

[c11] 11.A method to reduce boiloff rate of cryogen gas during a coldhead failure or power off condition in a zero boiloff cryogen cooled recondensing superconducting magnet assembly including superconducting magnet coils suitable for magnetic resonance imaging, the method comprising:
disposing a liquid cryogen in a cryogen pressure vessel to provide cryogenic temperatures to said magnet coils for superconducting operation;
surrounding said pressure vessel with a vacuum vessel spaced from said pressure vessel;
surrounding said pressure vessel with a first thermal shield spaced from said pressure vessel;
surrounding said first thermal shield with a second thermal shield spaced from said first thermal shield, said second thermal shield intermediate said vacuum vessel and said first shield;
thermally connecting a cryocooler by a first and a second thermal interface to said first and second thermal shields, respectively;
positioning a recondenser in the space between said pressure vessel and said first thermal shield and thermally connected by a thermal interface to said cryocooler

to recondense, back to liquid, cryogen gas provided from said pressure vessel; and

returning the recondensed liquid cryogen to said pressure vessel;

wherein said second thermal shield surrounding said first thermal shield reduces a radiation heat load from said first thermal shield to said pressure vessel lowering boiloff of cryogen gas under conditions of failure or power off of said cryocooler.

[c12] 12.The method of claim 11, wherein said cryocooler includes at least one of a single, double, and a three stage coldhead.

[c13] 13.The method of claim 12 further comprising:

disposing a penetration extending through said vacuum vessel to said pressure vessel, said penetration thermally isolated from said coldhead.

[c14] 14.The method of claim 13 including a third thermal interface between said cryocooler and said recondenser, and wherein sensible heat from said boiloff of cryogen gas cools down at least one of a coldhead sleeve of said coldhead, said penetration, and said first and second thermal shields.

[c15] 15. The method of claim 14 further comprising:

disposing tubing on at least one of said coldhead sleeve and respective said first and second thermal shields in fluid communication with said boiloff of cryogen gas, said tubing in further fluid communication with a pressure relief valve configured to selectively vent said boiloff of cryogen gas.

[c16] 16.The method of claim 15, wherein said tubing includes copper tubing in fluid communication between said first and second thermal shields, said tubing including a low conductive transition tubing in order to reduce conduction of heat load during normal operation of said coldhead, said low conductive tubing connecting copper tubing disposed around each of said first and second thermal shields.

[c17] 17.The method of claim 13, wherein said penetration includes a first penetration station and a second penetration station thermally connected by first and second penetration thermal interfaces to said first and second thermal shields, respectively.

[c18] 18.A zero boiloff liquid helium cooled recondensing superconducting magnet assembly suitable for magnetic resonance imaging comprising:
a helium pressure vessel to contain a liquid helium reservoir to provide cryogenic temperatures to said

magnet resonance imaging magnet assembly for superconducting operation;
a vacuum vessel surrounding said pressure vessel and spaced from said pressure vessel;
a first thermal shield surrounding said pressure vessel and spaced from said pressure vessel;
a second thermal shield surrounding said first thermal shield and spaced from said first thermal shield, said second thermal shield intermediate said vacuum vessel and said first shield; and
a recondenser and a cryocooler for cooling said recondenser to recondense helium gas formed in said pressure vessel back to liquid helium, said cryocooler thermally connected by a first and a second thermal interface to said first and second thermal shields, respectively;
wherein said second thermal shield surrounding said first thermal shield reduces a radiation heat load from said first thermal shield to said pressure vessel lowering boiloff of helium gas under conditions of failure or power off of said cryocooler.

[c19] 19.The zero boiloff superconducting magnet of claim 18, wherein said cryocooler includes at least one of a single, double, and a three stage coldhead.

[c20] 20.The zero boiloff superconducting magnet of claim 19 including a penetration extending through said vacuum

vessel to said pressure vessel, said penetration thermally isolated from said coldhead.

[c21] 21.The zero boiloff superconducting magnet of claim 20 including a third thermal interface between said cryocooler and said recondenser, and wherein sensible heat from said boiloff of helium gas cools down at least one of a coldhead sleeve of said coldhead, said penetration, and said first and second thermal shields.

[c22] 22. The zero boiloff superconducting magnet of claim 21 including tubing disposed on at least one of said coldhead sleeve and respective said first and second thermal shields in fluid communication with said boiloff of helium gas, said tubing in further fluid communication with a pressure relief valve configured to selectively vent said boiloff of helium gas.

[c23] 23.The zero boiloff superconducting magnet of claim 22, wherein said tubing includes copper tubing in fluid communication between said first and second thermal shields, said tubing including a low conductive transition tubing in order to reduce conduction of heat load during normal operation of said coldhead, said low conductive tubing connecting copper tubing disposed around each of said first and second thermal shields.

[c24] 24.The zero boiloff superconducting magnet of claim 20, wherein said penetration includes a first penetration station and a second penetration station thermally connected by first and second penetration thermal interfaces to said first and second thermal shields, respectively.